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Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	404302000400	*Total Pages*	55
First Named Inventor or Application Identifier			
Harry Teng, et al.			
Express Mail Label No.	EL265857098US		

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Joel R. Bischoff

APPLICATION ELEMENTS
See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents
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1. [X] **Fee Transmittal Form**
   (Submit an original, and a duplicate for fee processing)

2. [X] **Specification**   [Total Pages [31]]
   (preferred arrangement set forth below)
   - Descriptive title of the Invention
   - Cross References to Related Applications
   - Statement Regarding Fed sponsored R & D
   - Reference to Microfiche Appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings *(if filed)*
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure

3. [X] **Drawing(s)** *(35 USC 113)*   [Total Sheets [10]]

4. [X] **Oath or Declaration**   [Total Pages [3]]

   a. [X] Newly executed (original)

   b. [ ] Copy from a prior application (37 CFR 1.63(d))
   (for continuation/divisional with Box 17 completed)
   [Note Box 5 below]

      i. [ ] DELETION OF INVENTOR(S)
      Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b)

5. [X] **Incorporation By Reference** *(useable if Box 4b is checked)*
   The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

6. [ ] Microfiche Computer Program *(Appendix)*

7. Nucleotide and/or Amino Acid Sequence Submission
   (if applicable, all necessary)

   a. [ ] Computer Readable Copy

   b. [ ] Paper Copy (identical to computer copy)

   c. [ ] Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

8. [ ] Assignment Papers (cover sheet & document(s))

9. [ ] 37 CFR 3.73(b) Statement   [X] Power of Attorney
   (when there is an assignee)

10. [ ] English Translation Document *(if applicable)*

11. [ ] Information Disclosure Statement (IDS)/PTO-1449   [ ] Copies of IDS Citations

12. [ ] Preliminary Amendment

13. [X] Return Receipt Postcard (MPEP 503)
   (Should be specifically itemized)

14. [X] Small Entity Statement(s)   [ ] Statement filed in prior application, Status still proper and desired

15. [ ] Certified Copy of Priority Document(s)
   (if foreign priority is claimed)

16. [ ] ....
   ....
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   ....

17. If a CONTINUING APPLICATION, *check appropriate box and supply the requisite information:*

[ ] Continuation   [ ] Divisional   [ ] Continuation-in-part (CIP) of prior application No:

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sf-730370

☒ If a paper is untimely filed in the above-referenced application by applicant or his/her representative, the Assistant Commissioner is hereby petitioned under 37 C.F.R. § 1.136(a) for the minimum extension of time required to make said paper timely. In the event a petition for extension of time is made under the provisions of this paragraph, the Assistant Commissioner is hereby requested to charge any fee required under 37 C.F.R. § 1.17(a)-(d) to **Deposit Account No. 03-1952.** However, the Assistant Commissioner is **NOT** authorized to charge the cost of the issue fee to the Deposit Account.

The filing fee has been calculated as follows:

FOR	NUMBER FILED	NUMBER EXTRA	RATE	CALCULATIONS
TOTAL CLAIMS	19 - 20 =	0	x $18.00	$0
INDEPENDENT CLAIMS	2 - 3 =	0	x $78.00	$0
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ $260.00	$0
			BASIC FEE	$760.00
		TOTAL OF ABOVE CALCULATIONS =		$760.00
Reduction by 1/2 for filing by small entity (Note 37 C.F.R. §§ 1.9, 1.27, 1.28). If applicable, verified statement must be attached.				$380.00
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Dated: August 4, 1999

Respectfully submitted,

By: _____
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sf-730370

Docket No. 404302000400

Applicant/Patentee: Teng, et al.	Docket No.: 404302000400
Serial No./Patent No.: Unassigned	

Filed on/Issued : _____, 1999

For: METHOD AND APPARATUS FOR REDUCTION OF TRAPEZOIDAL DISTORTION AND IMPROVEMENT OF IMAGE SHARPNESS IN AN OPTICAL IMAGE CAPTURING SYSTEM

VERIFIED STATEMENT CLAIMING SMALL ENTITY STATUS
37 C.F.R. §§ 1.9(f) AND 1.27(c) — SMALL BUSINESS CONCERN

I hereby declare that I am

☐ the owner of the small business concern identified below:

☒ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF CONCERN: SecuGen Corporation

ADDRESS OF CONCERN: 1740 Technology Drive, Suite 290, San Jose, CA 95110

I hereby declare that the above identified small business concern qualifies as a small business concern as defined in 13 C.F.R. § 121.12, and reproduced in 37 C.F.R. § 1.9(d), for purposes of paying reduced fees to the United States Patent and Trademark Office, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention, entitled METHOD AND APPARATUS FOR REDUCTION OF TRAPEZOIDAL DISTORTION AND IMPROVEMENT OF IMAGE-SHARPNESS IN AN OPTICAL IMAGE CAPTURING SYSTEM by inventor(s) Harry H. Teng and Sung-Chan Jo described in

☒ the specification filed herewith with title as listed above.

☐ the application identified above.

☐ the patent identified above.

If the rights held by the above identified business concern are not exclusive, each individual, concern or organization having rights in the invention must file separate verified statements averring to their status as small entities, and no rights to the invention are held by any person, other than the inventor, who would not qualify as an independent inventor under 37 C.F.R. § 1.9(c) if that person made the invention, or by any concern which would not qualify as a small business concern under 37 C.F.R. § 1.9(d), or a nonprofit organization under 37 C.F.R. § 1.9(e).

Each person, concern or organization having any rights in the invention is listed below:

☒ no such person, concern, or organization exists.

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NAME	ADDRESS	TYPE
		☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 C.F.R. § 1.27)

I acknowledge the duty to file, in this application or patent, notification or any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 C.F.R. § 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

PTO/SB/10 (10-92)
sf-728313

I, Jun Young Ahn, President & CEO of SecuGen Corporation, declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct.

SIGNATURE: _____   Executed on: 7/30/99

NAME: Mr. Jun Young Ahn

TITLE : President & CEO

ADDRESS: 1740 Technology Drive, Suite 290, San Jose, CA 95110

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Serial No _____

Docket No 404302000400

METHOD AND APPARATUS FOR REDUCTION OF TRAPEZOIDAL DISTORTION AND IMPROVEMENT OF IMAGE SHARPNESS IN AN OPTICAL IMAGE CAPTURING SYSTEM

Inventors:

Harry H. Teng

Sung-Chan Jo

FIELD OF THE INVENTION

The present invention relates to an optical acquisition apparatus for use with an image capturing and recognition system. In particular, the present invention includes an optical acquisition apparatus for reducing or substantially eliminating trapezoidal distortion in images of patterned objects and allowing such images to be more sharply focused.

BACKGROUND

Patterned object recognition systems are becoming common in industrial and commercial settings and have a variety of uses. For example, such systems can be used in scanners for the scanning of text, drawings, and photographs. Recently, manufacturers have been attempting to reduce costs associated with pattern recognition systems to make them more viable for consumer use. One such consumer application for pattern recognition systems includes fingerprint acquisition and recognition. Such a system is useful, for example, to enhance computer security by reading a potential user's fingerprint to compare with the fingerprints of users authorized to use the computer or access certain files or functions of the computer. Such a system could, for example, take the place of a security system that uses a login name and password.

The first thing such a fingerprint recognition system, or any pattern recognition system, must be able to do is to accurately acquire the fingerprint, or other pattern, for analysis. A number of mechanisms exist for such acquisition of

pattern data. For example, U.S. Patent Nos. 3,975,711; 4,681,435; 5,051,576; 5,177,435 and 5,233,404 all disclose apparatuses for acquiring an image of a patterned object.

5   Figure 1 shows a schematic diagram of one such prior art optical fingerprint capturing and recognition system. In Figure 1, an optical recognition system 108 includes a light source 112, an optical triangular prism 110, a lens assembly 114, an image sensor 116, and a storage and processing unit 125. The prism 110 includes an imaging surface 118, a light receiving surface 120, and a viewing

10   surface 122. Imaging surface 118 is the surface against which a patterned object, such as a fingerprint, is placed for imaging. The light source 112, which may, for example, be a light emitting diode (LED), is placed adjacent to light receiving surface 120 and generates incident light 124 that is transmitted to the optical prism 110. The optical prism 110 is an isosceles right triangle, with the angle

15   opposite the imaging surface 118 being approximately 90 degrees and the other two "base" angles (that is, the two angles of an isosceles prism that are equal) each being approximately 45 degrees.

Generally, incident light 124 strikes imaging surface 118 at an angle 126 with

20   the incident surface normal line 115. Angle 126 is greater than the critical angle 128. In general, a critical angle is measured between an incident light ray and a normal line to a surface. If incident light strikes a surface at an angle greater than the critical angle, the incident light will undergo total internal reflection off the surface, if the incident light strikes the surface at an angle less than the critical

25   angle, the incident light will substantially pass through the surface. Accordingly, critical angle 128 is the angle with the normal line to the imaging surface 118 above which incident light will totally internally reflect from imaging surface 118 and pass out of prism 110 as reflected light 130 through viewing surface 122.

30   Reflected light 130 passes through lens assembly 114 located adjacent to viewing surface 122. Lens assembly 114 may contain one or more optical lenses.

Thereafter, light from lens assembly 114 is captured by image sensor 116. Image sensor 116, which may, for example, be a charge coupled device (CCD) or a complementary metal oxide semiconductor (CMOS) device, captures optical light images and converts them to electrical signals. Such image sensors are well

5   known to those skilled in the art. The electrical signals are then transmitted to the storage and processing unit 125.

Storage and processing unit 125 may include a memory unit, a processor and an analog to digital converter (not shown). The analog to digital converter

10   converts the analog electrical signals from the image sensor 116 into digital data. The memory is used to store the digital data and algorithms for comparing a captured fingerprint image with a stored fingerprint image. The processor compares the captured digital data with data previously stored in memory based on an algorithm for comparing such data. The processor may also analyze the

15   captured digital data for purposes different from comparison with stored data. Such storage and processing units are known to those skilled in the art and can include standard personal computers equipped with appropriate software. Algorithms for processing and comparison of image data are disclosed, for example, in U.S. Patent Serial Nos. 4,135,147 and 4,688,995 each of which is

20   incorporated in its entirety by reference.

When a fingerprint is placed on the optical prism's imaging surface 118, ridges 111 of the fingerprint contact imaging surface 118, and valleys 109 of the fingerprint remain out of contact with imaging surface 118. Thus, in fingerprint

25   valleys 109 incident light 124 entering optical prism 110 from light source 112 undergoes total internal reflection at imaging surface 118 if the incidence angle of the incoming light exceeds the critical angle of the optical prism 110. However, at ridges 111 of a fingerprint some of incident light 124 is absorbed and scattered off the fingerprint ridge. As used herein, the term "scattered" indicates light

30   which, after striking an irregular surface, is radiated or irregularly reflected off the irregular surface in multiple directions.

As a result of this scattering and/or absorption, there is less than total internal reflection of incident light 124 at fingerprint ridges 111. Thus, the intensity of reflected light 130 leaving prism 110 from the valleys 109 of a fingerprint is of greater intensity than reflected light 130 leaving prism 110 from ridges 111. The lower intensity reflected light 130 from ridges 111 translate into darker regions to indicate the presence of an object at the point of incidence between the light beam and the fingerprinting surface. Conversely, higher intensity reflected light 130, such as that which undergoes total internal reflection, translates into brighter regions to indicate the absence of an object at the point of incidence between the incident light 124 and the imaging surface 118. This allows distinguishing the darker fingerprint ridges 111 from the relatively brighter fingerprint valleys 109. Because absorption of incident light at fingerprint ridges 111 is primarily responsible for creating a fingerprint image, system 108 is referred to as an "absorption" imaging system.

The above described system allows capturing an optical fingerprint image and processing the electrical representation of the optical fingerprint image. However, in regions of fingerprint ridges 111, incident light 124 still undergoes some total internal reflection and some scattering in a direction parallel to reflected light 130. Thus, the difference in intensity between reflected light 130 from fingerprint valleys 109 and fingerprint ridges 111 can be relatively low. That is, the contrast between fingerprint ridges 111 and valleys 109 in the fingerprint image can be relatively low. This can make image acquisition, processing, and comparison relatively difficult.

Additionally, in optical recognition system such as optical recognition system 108 it can be desirable that the diameter of the first lens in lens assembly 114 be smaller than the image of a fingerprint on viewing surface 122. This both allows optical recognition system 108 to be relatively small and can be less expensive to manufacture.

However, as shown in Figure 2, in an absorption type system such as system 108, if the diameter of the first lens of lens assembly 114 is smaller than the fingerprint on imaging surface 118, then the lens assembly 114 must generally be

5   placed relatively far from viewing surface 122. This allows the image of a fingerprint captured by system 108 to be relatively sharp all the way to the edges of the fingerprint image. That is, if lens assembly 114 is placed too close to viewing surface 122, the edges of a fingerprint image could be lost or distorted near the edges of the image. This is because in an absorption system such as

10   system 108, the light rays which generate the image of the fingerprint must be substantially parallel for the image to be in focus. And, if the first lens in lens assembly 114 is smaller than the fingerprint in imaging surface 118, then the light rays from the edges of the fingerprint image that are parallel to light rays from areas closer to the center of a fingerprint image may not be able to enter lens

15   assembly 114. This can cause the edges of a fingerprint image to be out of focus or lost.

Thus, as shown in Figure 2, if the lens assembly for optical recognition system 108 were placed where lens assembly 114' is shown (in phantom), then

20   substantially parallel rays of reflected light 130 and 130' would not enter lens assembly 114'. For this reason, system 108 would not produce a sharp image of a fingerprint placed on imaging surface 118 at points A and B if the lens assembly were placed at the location of lens assembly 114'.

25   Thus, as shown in Figure 2, in an absorption system, the reduction in size gained by manufacturing a relatively small first lens of lens assembly 114 can be lost because lens assembly 114 must be placed at a relatively large distance from viewing surface 122 in order to capture the entire fingerprint image using light rays that are substantially parallel. For this reason, making optical recognition

30   system 108 relatively compact can be problematic. Additionally, a relatively

large distance between viewing surface 122 and lens assembly 114 can cause loss of contrast in the fingerprint image due to light interference.

Further, when the first lens in lens assembly 114 is smaller than an image of a fingerprint at viewing surface 122, a phenomenon known as trapezoidal distortion can occur in optical recognition system 108. Trapezoidal distortion in an imaging system has the effect of making the image of a square created by the system appear as a trapezoid.

Figure 2 is a schematic illustration showing why trapezoidal distortion arises in optical recognition system 108. Incident light 124 from light source 112 enters prism 110 and reflects off imaging surface 118, imaging object AB. Reflected light 130 then passes out of viewing surface 122 and to lens assembly 114 at points A' and B' to form object A'B'. Viewing object AB through viewing surface 122, object AB would appear to be located at an "apparent image" object ab. Specifically, point A appears to be at point a, a distance aa' from viewing surface 122 and point B appears to be at point b, a distance bb' from viewing surface 122. The distance that an apparent image of an object appears from viewing surface 122 is given by the actual distance the object is from viewing surface 122 divided by the index of refraction n of prism 110. Specifically, the distance aa' is given by:

$$aa'=Aa'/n,$$

where n is the index of refraction of prism 110. Similarly,

$$bb'=Bb'/n.$$

Trapezoidal distortion occurs when the light path length from the apparent image of an object to the lens plane 107 of lens assembly 114 is different for different parts of the imaged object and the object lens of the lens assembly 114 is smaller

than the image of the fingerprint through viewing surface 122. Specifically, trapezoidal distortion occurs in system 108 because the distance aA' is longer than the distance bB' and lens assembly 114 has a smaller diameter than the distance a'b' on viewing surface 122.

Another consequence of distance aA' being larger than distance bB' is that an image of an object which is sharply focused at each part of the image can be difficult to obtain. More generally, whenever the light path length from the apparent image of an object to the lens plane, and ultimately image sensor, of a lens assembly is different for different parts of the imaged object, parts of the image of the object at the lens plane may be in relatively sharp focus and parts of the image may be out of focus.

To correct both the problems of trapezoidal distortion and having a portion of an image of an object which is out of focus, prior art manufacturers have tilted the lens plane 107 of lens assembly 114 and image sensor 116 to increase the distance bB' and decrease the distance aA' to a point where the two distances are approximately equal. However, it is a property of an isosceles right prism (that is, a triangular prism in which the base angles measure approximately 45 degrees and the non-base angle, or apex angle, measures approximately 90 degrees), that reflected light 130 exits prism 110 substantially normal to viewing surface 122. That is, no refraction of reflected light 130 occurs as it exits viewing surface 122. Further, generally, the larger the angle of incidence on a surface of a transparent object, the greater the portion of incident light that is reflected from the surface. Thus, while tilting lens assembly 114 and the sensor can reduce trapezoidal distortion and increase image sharpness, it also causes greater reflection of reflected light 130 off the surface of lens assembly 114, and the surface of image sensor 116, because reflected light 130 strikes lens assembly 114 at a greater angle of incidence. This reduces the intensity of light entering image sensor 116, making image processing and comparison more difficult.

Additionally, the relative placement of light source 112 and lens assembly 114 make it possible for stray light 113 emitted by light source 112 to enter lens assembly 114. This can generate additional background "noise" light which can further reduce the quality of a captured image and make image processing more difficult.

To overcome some of the difficulties associated with the type of absorption image acquisition system described above, acquisition systems have been designed which are based primarily on "scattering" mechanisms rather than absorption mechanisms. One such acquisition system is disclosed by U.S. Patent No. 5,233,404 issued to J. Lougheed et al. on August 3, 1993 (Lougheed et al.). Figure 3 is a schematic diagram illustrating the image acquisition portion of the apparatus disclosed by Lougheed et al. As shown in Figure 3, a prior art image acquisition system 208 includes a trapezoidal prism 210, a light source 212, a lens assembly 214 and an image sensor 216. The trapezoidal prism 210 includes at least an imaging surface 218, a light receiving surface 220, and a viewing surface 222.

The imaging surface 218 is the surface against which an object to be imaged, such as a fingerprint, is placed. The light source 212 is located adjacent to and facing the light receiving surface 220 which is substantially parallel to imaging surface 218. Thus, incident light 224 emitted by light source 212 projects light through prism 210 and onto imaging surface 218 at an angle which is generally less than the critical angle 228 of prism 210. Therefore, in the valleys 209 of a fingerprint placed against imaging surface 218 where the fingerprint is not in contact with imaging surface, total internal reflection does not occur and incident light 224 passes through imaging surface 218. At points where fingerprint ridges 211 are in contact with imaging surface 218, incident light 224 strikes the fingerprint ridge to generate scattered (or equivalently, irregularly reflected) light 230. Scattered light 230 propagates back into prism 210 in substantially all directions including the direction of lens assembly 214, located adjacent to

viewing surface 222. Scattered light passes through viewing surface 222 and into lens assembly 214 to be detected by image sensor 216, which, as above, can be a CCD, CMOS or other type of detector.

5 In the region of a fingerprint valley 209, incident light 224 passes through imaging surface 218. And, in the area of a fingerprint ridge 211, incident light 224 scatters off imaging surface 218 to be picked up by lens assembly 214 and image sensor 216. Accordingly, the image of the fingerprint is relatively bright at fingerprint ridges 211 and relatively dark at fingerprint valleys 209. Because

10 scattered light 230 is picked up by the image sensor 216, this type of system is referred to as a "scattering" system.

The difference in intensity, or ratio of intensity, between the ridges and valleys in a fingerprint image created by such a scattering system can be greater than the

15 difference in intensity, or ratio of intensity, between the ridges and valleys of a fingerprint image created in an absorption system as shown in Figure 1. As a result, the fingerprint image created by such a scattering system can display higher contrast between fingerprint ridges and valleys than an image created by an absorption system. Thus, the image can be more accurately acquired by the image

20 sensor 216. This can reduce errors in subsequent fingerprint comparisons performed by the system.

Additionally, it is a property of a scattering system that the rays of light which enter lens assembly 214 to produce an image of a fingerprint in a scattering

25 system do not need to be parallel to produce a sharp image. Thus, if the first lens in lens assembly 214 is smaller than the image of the fingerprint in viewing surface 222, lens assembly 214 can still be placed relatively close to viewing surface 222 without loss of image sharpness near the edges of the image.

30 However, a trapezoidal prism such as prism 210 can be more expensive to manufacture than a triangular prism such as prism 110, shown in Figure 1. This is

because, among other reasons, there is an extra surface to polish. This can increase the price of an imaging system such as imaging system 208, making it less viable for consumer use.

5   Additionally, because of differences in scattered light path lengths from different portions of the apparent image of the fingerprint in prism 210 to lens assembly 214, image acquisition system 208 can cause portions of a fingerprint image to be out of focus in a manner similar to that of optical recognition system 108. Additionally, though not shown in Figure 3, if the first lens in lens assembly

10   214 of image acquisition system 208 is smaller than a fingerprint image on viewing surface 222 the differences in scattered light path lengths from different portions of the apparent image of the fingerprint in prism 210 to lens assembly 214 and image sensor 216 can also cause trapezoidal distortion.

15   As the above discussion makes clear, there is a need for improved image acquisition apparatus for use with patterned object recognition systems. Specifically, an image acquisition apparatus which produces an image having reduced or substantially eliminated trapezoidal distortion would be desirable. Additionally, an image acquisition system which generates an image in which

20   substantially the entire image is in focus is also desirable. The image acquisition system should also be relatively compact and inexpensive to manufacture.

SUMMARY OF THE INVENTION

The present invention includes a compact image acquisition apparatus which

25   produces a high contrast, low distortion image which has reduced or substantially no trapezoidal distortion. Additionally, the image acquisition system of the present invention can be relatively low cost to manufacture. The apparatus includes a light refractor having an imaging surface against which a patterned object is to be placed to form an apparent image of the patterned object in the light

30   refractor, a further surface, and a viewing surface. The viewing surface is adjacent to the imaging surface and forms an angle γ therewith. An image of the

patterned object is projected through the viewing surface. The apparatus also includes a lens adjacent to the viewing surface for receiving and focusing an image of a patterned object. The lens has a lens plane which is perpendicular to an optical axis of the lens and which forms an angle δ with the viewing surface. The angles γ and δ are formed to substantially equalize a path length of a first light ray traveling from one part of the apparent image of the patterned object to the lens plane, and ultimately, to the image sensor, with a path length of any other light ray substantially parallel to the first light ray and traveling from another part of the apparent image of the patterned object to the lens plane, and ultimately, the image sensor. Preferably, this is achieved by fixing angles γ and δ to conform to the equation:

$$0.7 \leq (n^2 - \sin^2\delta)^{1/2}(\cot\gamma)(\sin\delta)+\sin^2\delta \leq 1.30.$$

In another aspect of the present invention, preferably, every point of the portion of the imaging surface against which an object to be imaged is to be placed is able to have at least one light ray scattered therefrom such that the intersection of the light ray and the viewing surface form an angle, adjacent to the intersection of the viewing surface and the imaging surface, which is less than 90 degrees.

In yet another aspect of the present invention, a method of generating an image of a patterned object includes providing a light refractor having an imaging surface, a viewing surface, and a further surface. An angle γ is formed between a plane defined by the viewing surface and a plane defined by the imaging surface. A patterned object is placed against the imaging surface and incident light is projected into the light refractor. The incident light is scattered off the imaging surface and patterned object and through the viewing surface. A lens is provided adjacent to the viewing surface and an angle δ is formed between the focal plane of the lens and the plane defined by the viewing surface. The angles γ and δ are fixed to substantially equalize a path length of a first light ray traveling from one part of an apparent image of the patterned object formed in the light refractor to

the lens plane, and ultimately the image sensor, with a path length of any other light ray substantially parallel to the first light ray and traveling from another part of the apparent image of the patterned object to the lens plane and image sensor. Preferably, the angles γ and δ are fixed so that they are related by the equation:

5

$$0.7 \le (n^2 - \sin^2\delta)^{\frac{1}{2}}(\cot\gamma)(\sin\delta)+\sin^2\delta \le 1.30$$

Additionally, it is preferable that the portions of the imaging surface to be used for imaging are each able to have at least one light ray scattered therefrom such that the intersection of the light ray and the viewing surface form a first

10 angle, adjacent to the intersection of the viewing surface and the imaging surface, which is less than 90 degrees.

The apparatus and method discussed above allow forming an image of a patterned object which has reduced, or is substantially free of, trapezoidal

15 distortion and which can generate an image the entirety of which is in relatively sharp focus. This advantageously facilitates more accurate processing and comparison of patterned object images.

BRIEF DESCRIPTION OF THE DRAWINGS

20 Figure 1 is a schematic of a prior art image acquisition apparatus which utilizes an absorption image acquisition technique.

Figure 2 is a schematic of the image acquisition apparatus of Figure 1 illustrating trapezoidal distortion.

Figure 3 is a schematic of a second prior art image acquisition apparatus

25 which utilizes a scattering image acquisition technique.

Figure 4 is a schematic diagram of an image acquisition system including a prism, light source, lens assembly, and image sensor, in accordance with the present invention.

Figure 5 is a perspective view of the prism and light source shown in Figure 4.

30 Figure 6 is a schematic diagram of the image acquisition system shown in Figure 4 illustrating how trapezoidal distortion is reduced.

Figure 7 is a schematic diagram showing a lens assembly which can be used with the image acquisition system shown in Figure 4.

Figure 8 is a schematic diagram of the image acquisition system shown in Figure 4 illustrating preferred prism and lens assembly configuration.

5 Figure 9 is a schematic diagram showing an alternate embodiment of a prism which can be used with the image acquisition system of the present invention illustrating a scattered light ray path.

Figure 10 is a schematic diagram of the prism shown in Figure 9 illustrating an alternate scattered light ray path.

10

DETAILED DESCRIPTION

Figures 4 and 5 show a patterned object image acquisition system 308 in accordance with the present invention. Acquisition system 308 preferably includes a triangular prism 310, a light source 312, a lens assembly 314, and an

15 image sensor 316. Prism 310 is a five faced triangular prism the length of which extends into the plane of Figure 4. Prism 310 includes a rectangular, planar, imaging surface 318 against which an object to be imaged, such as a fingerprint 335, is placed. Prism 310 also includes a rectangular, planar, viewing surface 320 through which an image of a fingerprint 335 placed against imaging surface 318

20 passes out of prism 310. In the embodiment of Figures 4 and 5, viewing surface 320 also serves as a light receiving surface for allowing light to pass into prism 310. A light scattering surface 322 comprises a third, or further, rectangular, planar, surface of prism 310. For reasons detailed below, light scattering surface 322 is preferably a diffusive.

25

Light source 312 is preferably an elongated LED array consisting of a single row of light emitting diodes (LEDs) extending the length (into the plane of Figure 4) of prism 310. If such LEDs are used as light source 312, a diffusive cover can be placed between the LEDs and viewing surface 320 to provide more even

30 illumination of imaging surface 318. It is also within the ambit of the present invention, however, for light source 312 to be any other type of light source to

provide incident light into prism 310. Preferably, light source 312 is placed along an edge 338 of prism 310 which is opposite imaging surface 318. However, it is also within the ambit of the present invention to configure and locate a light source for acquisition system 308 in any other way. For example, other

5 configurations for light sources which can be used with the present invention are disclosed in commonly assigned, co-pending U.S. Patent Application Serial No. 09/191,428 for "High Contrast, Low Distortion Optical Acquisition System for Image Capturing" filed November 12, 1998, which is hereby incorporated by reference in its entirety. This includes placing light source 312 against viewing

10 surface 320 anywhere between edge 338 and the line 360 along viewing surface 320 formed by the intersection of viewing surface 320 and a perpendicular line to viewing surface 320 which intersects edge 365.

Lens assembly 314 is for receiving scattered light 330 from fingerprint 335

15 and focusing scattered light 330 onto image sensor 316. Lens assembly 314 can be a single lens or, preferably, can consist of multiple lenses. Most preferably, lens assembly 314 has a focal length of approximately 13.48 mm and is located approximately 13.5 mm from viewing surface 320. Additionally, as shown in Figure 7 which is a schematic diagram of one embodiment of lens assembly 314,

20 lens assembly most preferably consists of three lenses 904, 906, and 908 whose respective optical axes are aligned on a common optical axis 902. Lens 904 most preferably has a diameter of approximately 17.8 mm, and both lenses 906 and 908 most preferably have a diameter of approximately 6 mm. It is considered that any number of lenses be included in lens assembly 314.

25

Image sensor 316 captures optical light images from lens assembly 314 and converts them to electrical signals. Image sensor 316 can be a charge couple device ("CCD") or any other means of converting a light signal into either an analog or digital electrical signal. Preferably, image sensor 316 is a

30 complementary metal oxide semiconductor device. CCD and CMOS image sensors are well known by those skilled in the art. The electrical signals

generated by image sensor 316 can be processed using known means and used to compare input patterns, such as fingerprints. As noted in the Background section, such signal processing means are disclosed, for example, in U.S. Patent Nos. 4,135,147 and 4,688,995, which have been incorporated by reference.

5

To create an optical image of fingerprint 335 on image sensor 316, fingerprint 335 is placed against imaging surface 318. Incident light 324 from light source 312 passes through viewing surface 320 and into prism 310. Because light source 312 is located adjacent to edge 338, incident light 324 strikes scattering surface

10   322. As noted above, scattering surface 322 is preferably diffusive. As such, a relatively high portion of incident light 334 striking scattering surface 322 is internally scattered in prism 310. This scattered light then strikes imaging surface 318. Even if light scattering surface 322 is not diffusive, substantially all of incident light 324 will strike scattering surface 322 at an angle 323 which is

15   greater than the critical angle for scattering surface 322. Thus, incident light will reflect off scattering surface 322 and strike imaging surface 318. To enhance reflection of incident light off scattering surface 322 it is contemplated to place a mirrored face of a reflecting surface 381 towards scattering surface 322.

20   Because incident light 324 has been scattered or directly reflected off scattering surface 322, a relatively large percentage of incident light 324 will strike imaging surface 318 at an angle 327 less than the critical angle 328 of prism 310. Accordingly, incident light 324 which strikes imaging surface 318 at a region thereof where there is a fingerprint valley 309 will not undergo total

25   internal reflection and will substantially pass through imaging surface 318. Thus, substantially no light hitting an area of imaging surface 318 where there is a fingerprint valley 309 will be directed into the sensor 316. However, incident light 324 that strikes a region of imaging surface 318 where there is a fingerprint ridge 311 touching imaging surface 318 will substantially scatter, producing

30   scattered light 330. A portion of scattered light 330 will exit prism 310 via

viewing surface 320. Upon exiting prism 310, scattered light 330 will refract into lens assembly 314 which will focus scattered light 330 into image sensor 316.

Because incident light 324 can be scattered by scattering surface 322, incident light 324 provides relatively uniform illumination over imaging surface 318 which produces a relatively uniform image. Such a uniform image is desirable because it is easier to process and compare with other stored fingerprint data. To further increase the uniformity of illumination over imaging surface 318, the portion of viewing surface 320 facing light source 312 can be streaked by etching lines 370, shown in Figure 5, on viewing surface 320. Lines 370 run the length of prism 310 and parallel to apex 338. Lines 370 act to diffuse light emitted from light source 312 as it passes through viewing surface 320.

In addition to the components discussed above, image acquisition system 308 preferably also includes a light blocking shield 350 on a portion of light receiving surface adjacent to light source 312. Preferably, light blocking shield runs the entire length of prism 310 (into the plane of Figure 4). Light blocking shield 350 is to reduce the amount of stray light from light source 312 which might enter lens assembly 314 and interfere with or cloud a fingerprint image. It is also considered that the surface of light blocking shield 350 facing the interior of prism 310 be mirrored. This mirroring can act to desirably increase the intensity of scattered light incident on imaging surface 318. In addition to, or instead of, light blocking surface 350, a second light blocking surface 352 can be placed between light source 312 and lens assembly 314. Light shield 352 preferably extends from viewing surface 320 at an angle to block stray light from light source 312 from entering lens assembly 314.

Because light source 312 is relatively narrow and located adjacent to edge 338 opposite imaging surface 318, substantially all incident light 324 reaching imaging surface 318 is reflected or scattered into the lens assembly 314. That is, almost no incident light 324 can be captured by the image sensor 316 without

scattering off the imaging surface 318 at the points of contact with fingerprint ridges 311. To further reduce the likelihood of incident light 324 which falls into the fingerprint valleys 309 reaching image sensor 316 through lens assembly 314, light source 312 is preferably configured not to extend past a line 360, shown in Figure 5, extending the length of prism 310 and defined by the intersection of a plane normal to viewing surface 320 and intersecting with edge 365, adjacent to imaging surface 318. If light source 312 is kept on the same side of this line as apex 338, then substantially no incident light 324 emitted perpendicularly from light source 312 will reach image sensor 316 without scattering off of the fingerprint ridges 311.

By minimizing the incident light 324 from light source 312 that is directly incident on imaging surface, there is substantially no total internal reflection of incident light 324 from regions of imaging surface 318 where there are fingerprint valleys 309. This means that substantially no light from these valley regions passes through viewing surface 320 and into lens assembly 314. Rather, substantially all the light passing into lens assembly 314 from imaging surface 318 is scattered from fingerprint ridges 311 on imaging surface 318. This provides a fingerprint image having relatively high contrast between fingerprint ridges 311 and valleys 309. Such a high contrast fingerprint image is relatively easy to process and compare with other fingerprint images and can, therefore, advantageously increase processing accuracy.

Further, use of this scattering technique for image acquisition is achieved with a triangular prism, as opposed to a trapezoidal prism as disclosed in Lougheed, discussed in the Background section. Because triangular prisms can be more efficient to manufacture than trapezoidal prisms, image acquisition system 308 can advantageously be relatively less expensive to manufacture.

Moreover, scattered light generally scatters from an object in many directions, as opposed to substantially one direction. And, as noted in the Background, non-parallel scattered light can be used by a lens assembly to form a focused image of

an object. Thus, as shown in optical recognition system 318 in Figure 6, if the first lens of lens assembly 314 has a smaller diameter than the diagonal of fingerprint 335 in viewing surface 322, non-parallel scattered light rays can be used to produce a focused image of fingerprint 335. Accordingly, lens assembly

5   314 can be, but does not necessarily need to be, placed relatively close to viewing surface 320 without loss of image quality near the edges of a fingerprint image generated by system 308. This advantageously allows the image acquisition system 308 to be relatively compact and allows lens assembly 314 to be relatively low cost to manufacture.

10

Because, as shown in Figure 6, the diameter of a first lens of lens assembly 314 is smaller than the size of the fingerprint on viewing surface 318, trapezoidal distortion could result in a generated image. However, the image acquisition system of the current invention can reduce trapezoidal distortion in, and increase

15   the overall sharpness of, a produced image. As discussed in the Background section, trapezoidal distortion is manifested in an image having dimensions distorted from those of the actual object being imaged. Both trapezoidal distortion and portions of an image being out of focus can be caused by variation in path length of light from the apparent image of an object to lens assembly 314,

20   and ultimately image sensor 316, from one part of the imaged object to another. As shown in Figure 6, however, in image acquisition system 308, the path length of scattered light 330 from different points on the apparent image 335' of fingerprint 335 to lens assembly 314 and image sensor 316 is substantially the same. Specifically, path AA' is substantially equal to path BB' and path CC'.

25   Thus, trapezoidal distortion can advantageously be reduced and overall image sharpness can be increased. As shown in Figure 6, substantial equalization of paths AA', BB' and CC' is facilitated by tilting lens assembly 314 with respect to viewing surface 320.

30   However, unlike optical recognition system 108, shown in Figure 1, such tilting of lens assembly 314 does not severely reduce the intensity of the image

reaching image sensor 316. As noted in the background section with respect to optical recognition system 108, tilting lens assembly 114 causes reflected light 130 to strike the first element of lens assembly 314 at an angle to normal line thereof. This causes greater reflection of reflected light 130 from the surface of

5   lens assembly 114, thereby undesirably reducing image intensity at image sensor 116.

However, prism 310 preferably has an index of refraction higher than 1. Thus, scattered light 330 which strikes viewing surface 320 refracts away from the

10   normal to viewing surface 320 as it exits prism 310. As such, by tilting the lens plane 307 of lens assembly 314, scattered light 330 strikes lens assembly 314 at substantially 90 degrees. Thus, there is little or no loss in image intensity due to undue reflection of scattered light at the surface of lens assembly 314, and trapezoidal distortion can be reduced, and overall image sharpness can be

15   increased, without losing image intensity at image sensor 316.

Referring to Figure 8, the appropriate angle at which to tilt lens assembly 314 can be determined. In Figure 8, light rays 410 and 412 are scattered from imaging surface edge 414 and opposite imaging surface edge 416, respectively. Lens

20   plane 307 is a theoretical representation of lens assembly 314 as the thickness of the lens assembly goes to zero. Distance Aa is the distance from the apparent image of an object in prism 310 to lens plane 307 along light ray 410 and distance B'b is the distance from the apparent image of an object in prism 310 along light ray 412. In order to substantially eliminate trapezoidal distortion, distance Aa

25   must be substantially equal to distance B'b. Because B'b is the apparent depth of an object at edge B in prism 310, then, as discussed in the Background section:

$$B'b = Bb/n$$

where Bb is the distance from point B, at edge 416, to point b on prism 310. The requirement for substantial elimination of trapezoidal distortion and improvement in overall image sharpness can be expressed as:

$$Aa = Bb/n$$

(Eq. 1)

The angle of incidence of light ray 412 on viewing surface 320, that is, the angle between a normal line to viewing surface 320 and light ray 412 inside prism 310, is shown in Figure 8 as θ_1. The angle of refraction of light ray 412 after it passes out of prism 310 is shown as θ_2. Thus, by Snell's law:

$$n = \sin\theta_2/\sin\theta_1 \qquad \text{(Eq. 2)}$$

Also, using fundamental trigonometric relationships, it can be shown that:

$$ABcos\gamma + Bbcos\alpha' = Ab$$

(Eq. 3)

where AB is the length of the imaging surface of prism 310 from point A to point B; Ab is the length of segment Ab on viewing surface 320; α' is the angle between light ray 412 and viewing surface 320, which equals $90°-\theta_1$; and γ is the angle between imaging surface 318 and viewing surface 320 (also shown as angle 342 in Figure 8).

Finally, using the law of sines, it can be shown that:

$$AB/Bb = \cos\theta_1/\sin\gamma \qquad \text{(Eq. 4)}$$

Using equations 1, 2, 3, and 4 above, it can be shown that in order for trapezoidal distortion to be substantially eliminated, and overall image sharpness

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increased, the following condition relating the angles of prism 310 with the angle
which lens plane 307 forms with viewing surface 320 must be met:

$$(n^2 - \sin^2\delta)^{\frac{1}{2}}(\cot\gamma)(\sin\delta)+\sin^2\delta = 1 \qquad \text{(Eq. 5)}$$

Where, as shown in Figure 8, δ is the angle that lens plane 307 of lens assembly
314 forms with viewing surface 320. Thus, imaging system 308, in accordance
with the present invention, is preferably configured in accordance with equation 5
to substantially eliminate trapezoidal distortion and improve overall image
sharpness.

However, in manufacturing imaging system 308, achieving precise tolerances
for angles γ and δ can be difficult and expensive. Therefore, an imaging system
in accordance with the present invention and allowing for a 30% manufacturing
tolerance is preferably configured in accordance with the equation 6 below:

$$0.7 \leq (n^2 - \sin^2\delta)^{\frac{1}{2}}(\cot\gamma)(\sin\delta)+\sin^2\delta \leq 1.3 \qquad \text{(Eq. 6)}$$

More preferably, an imaging system in accordance with the present invention
and allowing for a 15% manufacturing tolerance is configured in accordance with
equation 7 below:

$$0.85 \leq (n^2 - \sin^2\delta)^{\frac{1}{2}}(\cot\gamma)(\sin\delta)+\sin^2\delta \leq 1.15 \qquad \text{(Eq. 7)}$$

Most preferably, an imaging system in accordance with the present invention
and allowing for a 7.5% manufacturing tolerance is configured in accordance with
equation 8 below:

$$0.925 \leq (n^2 - \sin^2\delta)^{\frac{1}{2}}(\cot\gamma)(\sin\delta)+\sin^2\delta \leq 1.075 \qquad \text{(Eq. 8)}$$

As noted above, by configuring imaging system 308 in accordance with one of
equations 5-8 above, trapezoidal distortion can be substantially reduced or
eliminated and overall image sharpness can be improved. This advantageously

facilitates more accurate image processing and comparison by an image acquisition system.

5   Prism 310 can be made of glass, acrylic or any other transparent material having an index of refraction higher than 1 (that of air). Prisms having the preferred index of refraction and angles are commercially available from Shinkwang Ltd. of Seoul, Korea and are fabricated of glass having the designation LaK-7 or LaK-8.

10   Lens assemblies such as lens assembly 314 are commercially available from Woorim Optical Systems Ltd. of Seoul, Korea and are preferably fabricated from a glass having the commercial designation of BK7. If more than one element is used in lens assembly 314, as shown in Figure 6, the individual elements can be aligned and spaced by placing them in a frame fabricated by plastic molding or

15   any other fabrication means as is known in the art.

      Light source 312 preferably consists of four standard LEDs positioned in a straight array on a circuit board. Powering of LEDs is well known by those skilled in the art. Image sensor 316 is preferably a CMOS type sensor and is

20   commercially available from Hyundai Electronics of Seoul, Korea, VLSI Vision, Ltd. of San Jose, California, or Omnivision Technologies Inc. of Sunnyvale, California.

      To secure the components of image acquisition into the relative positions as

25   shown in Figure 4, a frame having holding slots for each component can be plastic molded or otherwise fabricated. Light source 312 can be either placed in a holding slot adjacent to viewing surface 320 or attached directly to viewing surface 320 using adhesive as known in the art.

30   Equations 5-8 were derived assuming that the entire width AB of imaging surface 318 would be used in capturing an image. However, less than the entire

imaging surface of a prism can be used to capture an image. This may be the case, for example, if a triangular prism having an angle greater than or equal to 90 degrees is used as a light refractor. However, if the entire imaging surface of a prism is not used to image an object, a requirement in addition to being

5   configured according to equations 5-8 above is preferably met by the configuration of such an imaging system. To illustrate this additional requirement, Figure 9 shows a triangular prism 510 having an obtuse angle 541. Triangular prism 510 includes a planar imaging surface 518, a planar viewing surface 520 and a planar further surface 522. Figure 9 also shows a light source

10   512 which can be substantially the same as light source 312, and lens plane 507 of a lens assembly (not shown). A lens assembly used with prism 510 can be substantially the same as lens assembly 314.

As shown in Figure 9, a light ray 612 is scattered from point D on imaging

15   surface 518 and a light ray 610 is scattered from imaging surface 518 at point A. Prism 510 and lens plane 507 are configured in accordance with equation 5 above. Additionally, segment a'd' is parallel to lens plane 507. And, length D'd' is the apparent depth in prism 510 of the image of an object at point D on imaging surface 518. Thus, the length of segments Aa' and D'd' are the equal. Because

20   the index of refraction of prism 510 is greater than 1, as light ray 612 leaves prism 510 at point d', it will refract away from a normal line 620 to viewing surface 520.

Angle 545, labeled as α' in Figure 9, which is the angle formed by the intersection of light ray 612 and viewing surface 520, and is adjacent to the

25   intersection of the viewing surface and the imaging surface, is less than 90 degrees. Thus, as light ray 612 passes out of prism 510 and refracts away from normal line 620, it will travel in a path parallel to that of light ray 610 outside of prism 510. Therefore, the lengths of segments a'a and d'd are also equal. Accordingly, the total path lengths from the apparent image in prism 510 to the

30   lens plane 507, and ultimately the an image sensor (not shown) will be the same.

for an object on imaging surface 518 at both point A and point D. In this way overall image sharpness can be increased.

Referring now to Figure 10, which also shows prism 510, the path length from the apparent image in prism 510 of an object placed at point E on imaging surface 518 will not be equal to the path length from the apparent image in prism 510 of an object placed at point A on prism 510. Light ray 612 is a scattered light ray from an object placed at point E on imaging surface 518. As above, because prism 510 has an index of refraction which is greater than 1, as light ray 612 exits prism 510 at point e', it will refract away from normal line 620 to viewing surface 520. Therefore, because angle 545, labeled α', is greater than 90 degrees, the path of light ray 612 outside of prism 510 is not parallel to the path of light ray 610 outside of prism 510. Because light rays 610 and 612 are not parallel, the length of segment e'e will be different from the length of segment a'a. This means that the total path length from the apparent image in prism 510 to lens plane 507 will be different for an object at point E on imaging surface 318 than for an object at point A thereon. Thus, relatively large trapezoidal distortion and/or a relatively out of focus image will result.

As noted above, in order to avoid this, when a prism having a 90 degree or greater angle is used in an imaging system in accordance with the present invention, preferably, less than the entire width of the imaging surface is used to image an object. As shown above, when α' is less than 90 degrees, and the image capturing system is configured according to equations (5) through (8) above, trapezoidal distortion can be substantially eliminated. And, when α' is greater or equal to 90 degrees trapezoidal distortion can result. Thus, if less than the entire width of the imaging surface 518 of a prism is to be used to place an object to be imaged against, each portion of the imaging surface 518 to be used for imaging must be able to have at least one light ray scattered therefrom such that the intersection of the one light ray and the viewing surface 520 form an angle, α' in Figures 9 and 10, adjacent to the intersection of the viewing surface and the

imaging surface, which is less than 90 degrees. This criteria advantageously facilitates reduction or substantial elimination of trapezoidal distortion and increase in overall image sharpness in an imaging system configured in accordance with one of equations 5-8 above.

5

Prism 510, and light source 512 can be manufactured in substantially the same way and of the same materials as discussed above with respect to prism 310 and light source 312.

10   Many widely different embodiments of the present invention may be constructed without departing from the spirit and scope of the present invention. It should be understood that the present invention is not limited to the specific embodiments described in the specification. For example, though the above disclosed embodiment of the present invention are described with reference to

15   imaging a fingerprint, any other type of patterned object is contemplated to be imaged with the present invention.

CLAIMS

What is claimed is:

5   1. A compact apparatus for forming a high contrast, low distortion image of a
patterned object including:

a light refractor for reflecting and refracting light, the light refractor
including:

an imaging surface against which a patterned object to be imaged is to
10   be placed to form an apparent image of the patterned object in the
light refractor;

a viewing surface adjacent to the imaging surface and through which
an image of the object to be imaged is projected, the viewing
surface forming an angle γ with the imaging surface; and

15   a further surface adjacent to the imaging surface

at least one lens adjacent to the viewing surface and for receiving and
focusing an image of a patterned object projected through the viewing
surface, the lens having a lens plane which is perpendicular to an
optical axis of the lens, the lens plane forming an angle δ with the
20   viewing surface;

wherein the angles γ and δ are formed to substantially equalize a path
length of a first light ray traveling from one part of the apparent image
of the patterned object to the lens plane with a path length of any other
light ray substantially parallel to the first light ray and traveling from
25   another part of the apparent image of the patterned object to the lens
plane.

2. The apparatus of claim 1 wherein the angles γ and δ are related by the
equation:

30          $0.7 \leq (n^2 - \sin^2\delta)^{\frac{1}{2}}(\cot\gamma)(\sin\delta)+\sin^2\delta \leq 1.3$

3. The apparatus of claim 1 wherein the angles γ and δ are related by the equation:

$$0.85 \leq (n^2 - \sin^2\delta)^{1/2}(\cot\gamma)(\sin\delta)+\sin^2\delta \leq 1.15$$

4. The apparatus of claim 1 wherein the angles γ and δ are related by the equation:

$$0.925 \leq (n^2 - \sin^2\delta)^{1/2}(\cot\gamma)(\sin\delta)+\sin^2\delta \leq 1.075$$

5. The apparatus of claim 1 wherein the part of the imaging surface against which an object to be imaged is to be placed is able to have at least one light ray scattered from each portion thereof such that the intersection of the at least one light ray and the viewing surface form a first angle, adjacent to the intersection of the viewing surface and the imaging surface, which is less than 90 degrees.

6. The apparatus of claim 1 further including at least one light source located adjacent to the light refractor and for emitting incident light which enters the light refractor to create an image of the patterned object at the viewing surface.

7. The apparatus of claim 6 wherein:

the triangular prism includes:

a first edge opposite the imaging surface and adjacent to the viewing surface; and

the light source is a strip of light emitting diodes (LEDs) oriented towards and parallel with the viewing surface and adjacent to the first edge.

8. The apparatus of claim 1 wherein:

the at least one lens has a diameter;

the object to be imaged has a length dimension; and

the diameter of the at least one lens is smaller than the length dimension of the object to be imaged.

9. The apparatus of claim 2 wherein the part of the imaging surface against which an object to be imaged is to be placed is able to have at least one light ray scattered from each portion thereof such that the intersection of the at least one light ray and the viewing surface form a first angle, adjacent to the intersection of the viewing surface and the imaging surface, which is less than 90 degrees.

10. The apparatus of claim 3 wherein the part of the imaging surface against which an object to be imaged is to be placed is able to have at least one light ray scattered from each portion thereof such that the intersection of the at least one light ray and the viewing surface form a first angle, adjacent to the intersection of the viewing surface and the imaging surface, which is less than 90 degrees.

11. The apparatus of claim 4 wherein the part of the imaging surface against which an object to be imaged is to be placed is able to have at least one light ray scattered from each portion thereof such that the intersection of the at least one light ray and the viewing surface form a first angle, adjacent to the intersection of the viewing surface and the imaging surface, which is less than 90 degrees.

12. A method of imaging a patterned object comprising:

      providing a light refractor having an imaging surface, a viewing surface and a further surface;

      forming an angle γ between a plane defined by the viewing surface and a plane defined by the imaging surface;

      placing the patterned object against the imaging surface of the light refractor;

      projecting incident light into the light refractor;

      scattering the incident light off the imaging surface and patterned object and through the viewing surface;

      providing a lens adjacent to the viewing surface;

      forming an angle δ between the plane defined by the viewing surface and a lens plane of the lens;

fixing angles δ and angle γ to equalize a path length of a first light ray

traveling from one part of an apparent image of the patterned object in

the light refractor to the lens plane with a path length of any other light

ray substantially parallel to the first light ray and traveling from

5   another part of the apparent image of the patterned object to the lens

plane.

13. The method of claim 12 wherein the step of fixing angle δ and angle γ

includes relating angle δ and angle γ according to the equation;

10          $$0.7 \leq (n^2 - \sin^2\delta)^{\frac{1}{2}}(\cot\gamma)(\sin\delta)+\sin^2\delta \leq 1.3$$

14. The method of claim 13 wherein the step of fixing angle δ and angle γ

includes relating angle δ and angle γ according to the equation;

$$0.85 \leq (n^2 - \sin^2\delta)^{\frac{1}{2}}(\cot\gamma)(\sin\delta)+\sin^2\delta \leq 1.15$$

15

15. The method of claim 12 wherein the step of fixing angle δ and angle γ

includes relating angle δ and angle γ according to the equation;

$$0.925 \leq (n^2 - \sin^2\delta)^{\frac{1}{2}}(\cot\gamma)(\sin\delta)+\sin^2\delta \leq 1.075$$

20 16. The method of claim 12 wherein the step of placing the patterned object

against the imaging surface includes placing the patterned object against portions

of the imaging surface which are able to have at least one light ray scattered

therefrom such that the intersection of the at least one light ray and the viewing

surface form a first angle, adjacent to the intersection of the viewing surface and

25   the imaging surface, which is less than 90 degrees.

17. The method of claim 13 wherein the step of placing the patterned object

against the imaging surface includes placing the patterned object against portions

of the imaging surface which are able to have at least one light ray scattered

30   therefrom such that the intersection of the at least one light ray and the viewing

surface form a first angle, adjacent to the intersection of the viewing surface and the imaging surface, which is less than 90 degrees.

18. The method of claim 14 wherein the step of placing the patterned object against the imaging surface includes placing the patterned object against portions of the imaging surface which are able to have at least one light ray scattered therefrom such that the intersection of the at least one light ray and the viewing surface form a first angle, adjacent to the intersection of the viewing surface and the imaging surface, which is less than 90 degrees.

19. The method of claim 15 wherein the step of placing the patterned object against the imaging surface includes placing the patterned object against portions of the imaging surface which are able to have at least one light ray scattered therefrom such that the intersection of the at least one light ray and the viewing surface form a first angle, adjacent to the intersection of the viewing surface and the imaging surface, which is less than 90 degrees.

ABSTRACT OF THE INVENTION

An apparatus and method for acquiring an image of a patterned object such as a fingerprint including a light refracting device, a focusing lens, and a light source. The light refracting device can, for example, be a prism and includes an

5 imaging surface, a light receiving surface and a viewing surface. Incident light from the light source is projected through the light receiving surface and reflected off a surface other than the imaging surface. This reflected light is then projected onto the imaging surface to create an image of the patterned object from substantially all scattered light through the viewing surface. The lens is placed

10 adjacent to the viewing surface to focus the light on an image sensor. The apparatus is configured to reduce or substantially eliminate trapezoidal distortion and improve overall image sharpness in an image of an object created by the apparatus.
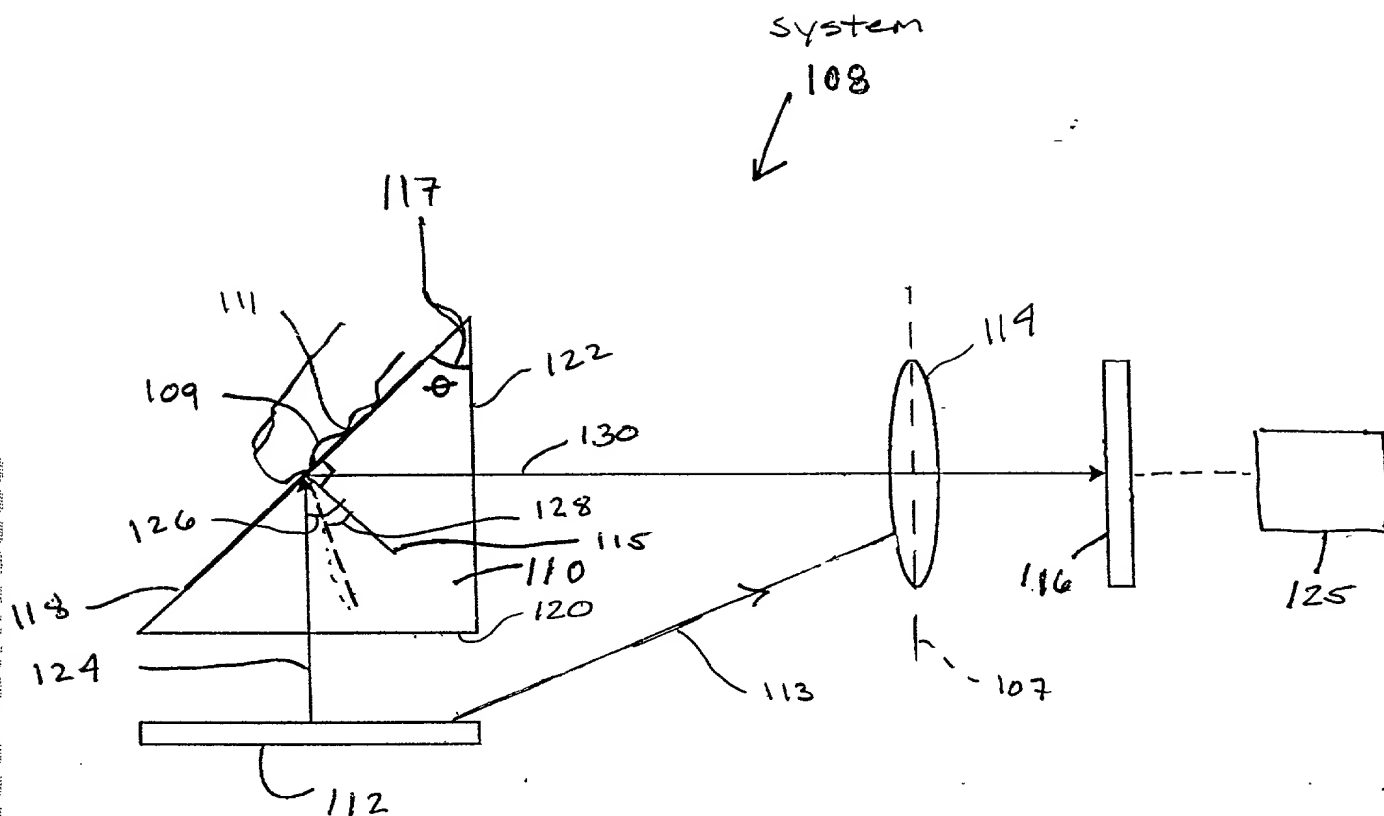
15

system
108

117

111

109

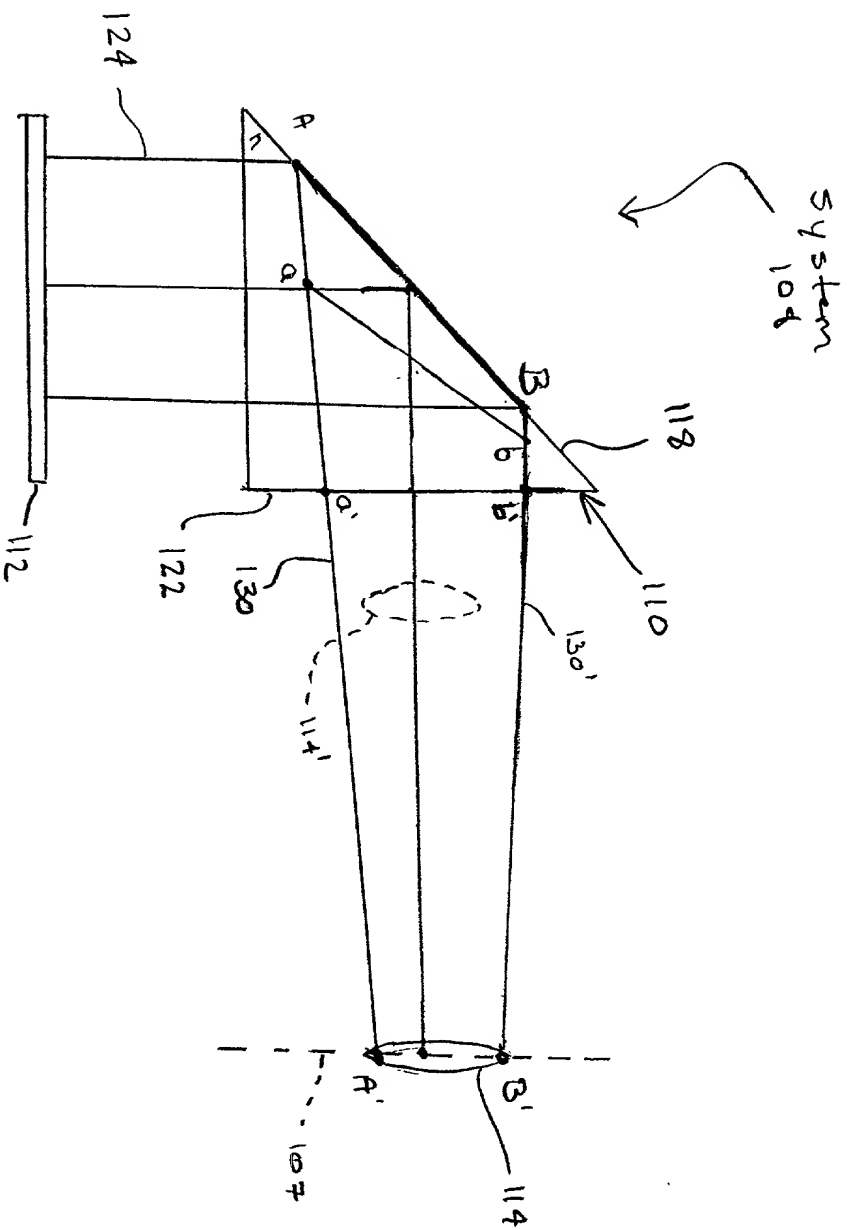122

130

126

128

115

118

110

124

120

112

114

113

107

116

125

φ

Fig. 1 (Prior Art)

Fig. 2 (Prior Art)

Fig- 3 (Prior Art)

365

318

360
310

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328

335

311

309

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381

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342

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323

322

324

320

338

314

350

312

352

341

307

316

Fig. 4

(First Embodiment)

System
308

Fig. 5

320

360

318

365

310

322

370

312

338

Fig. 6

System 308

Fig 7

902

904

906

908

Lens Assembly
314

Fig 8
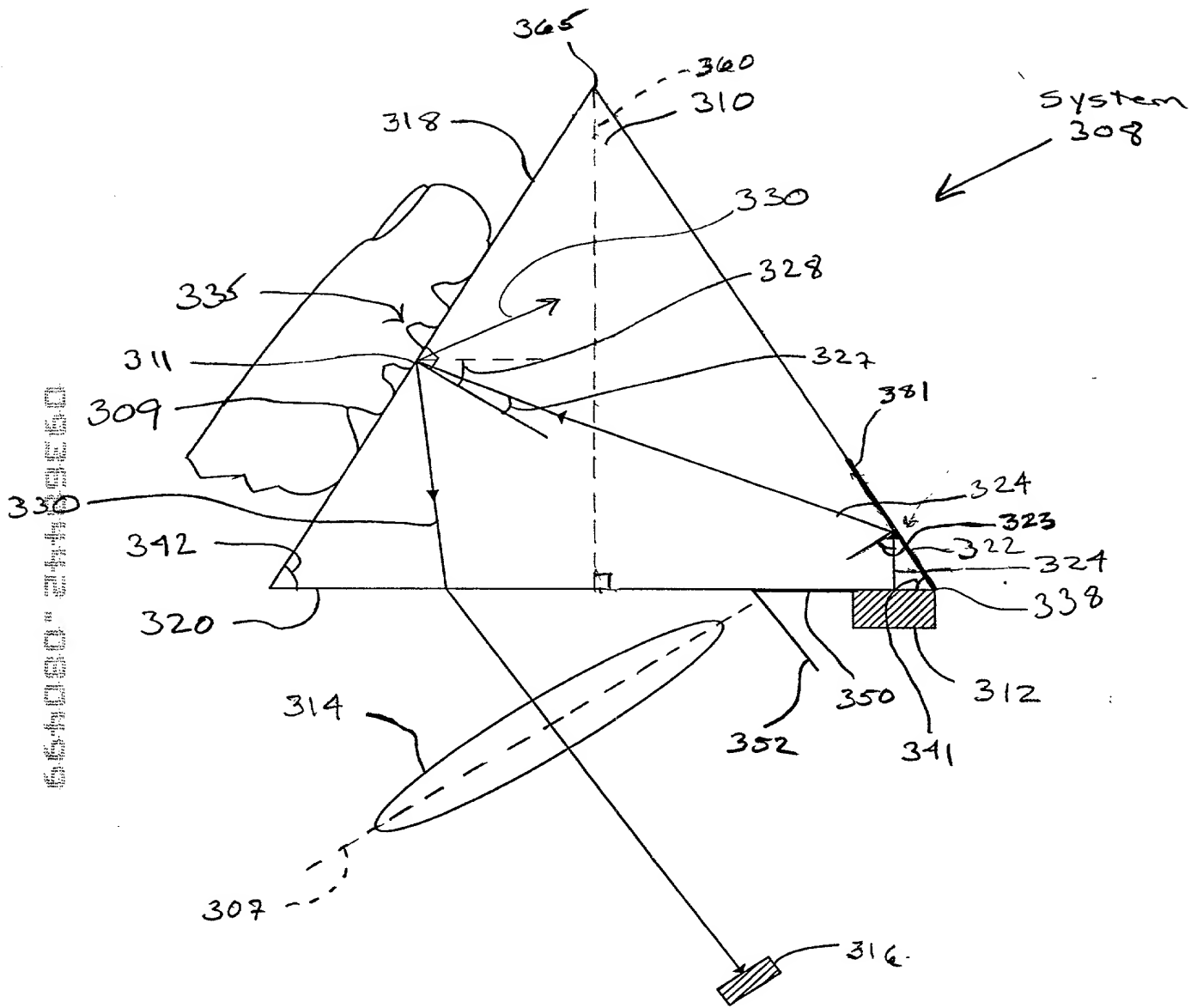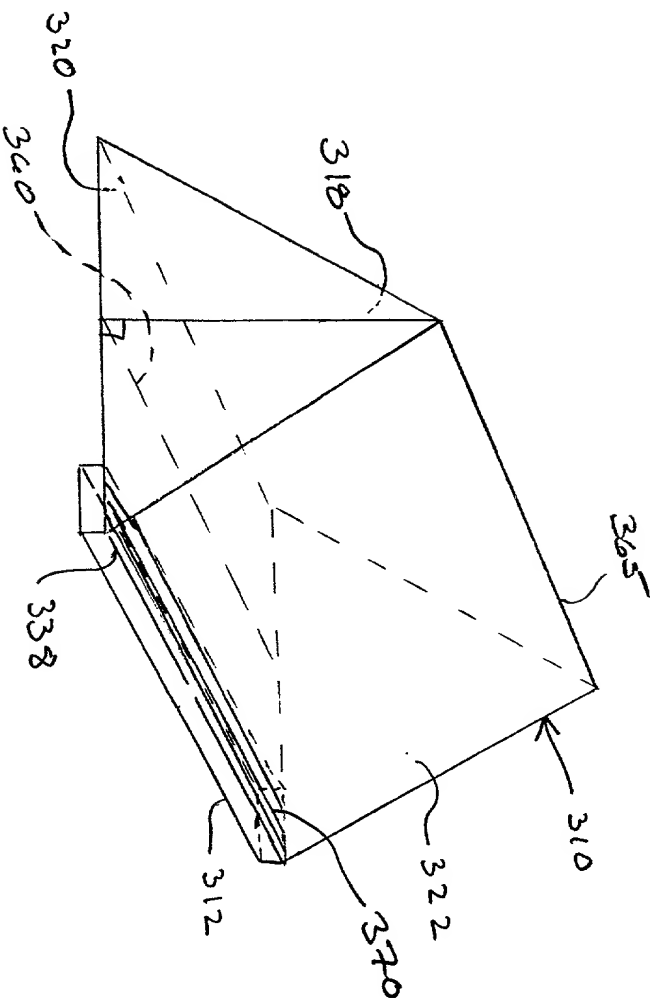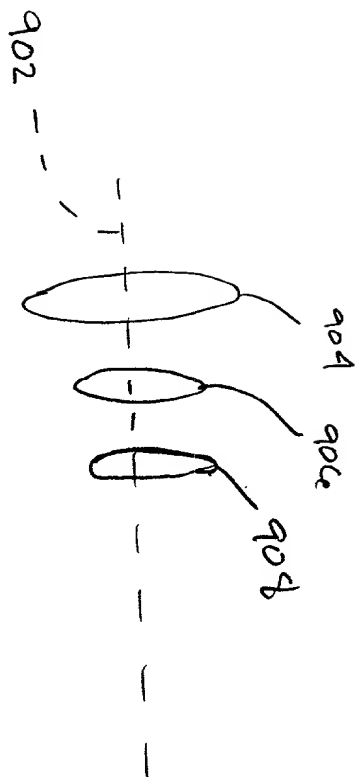
Fig. 9

Fig. 10

COMBINED DECLARATION AND POWER OF ATTORNEY
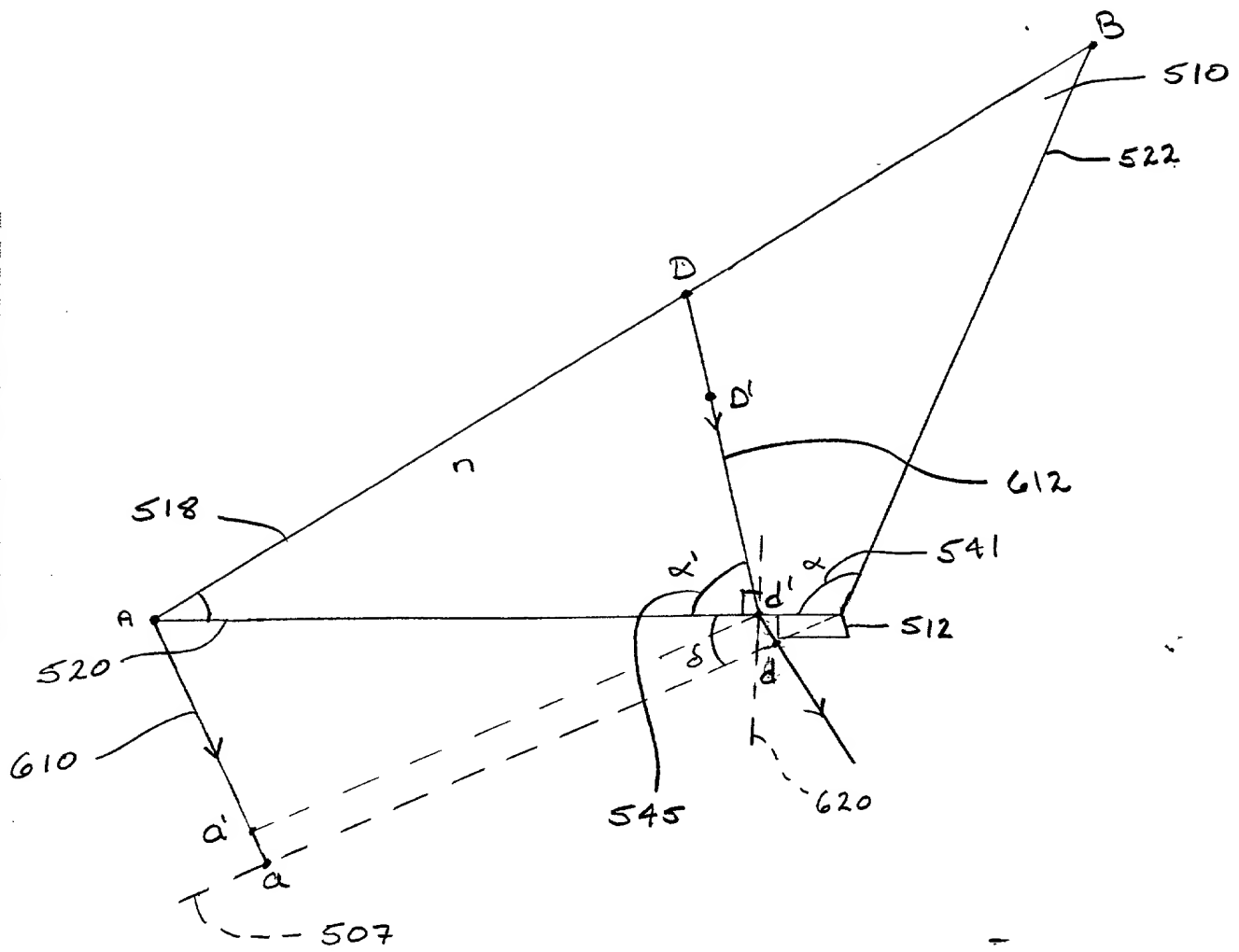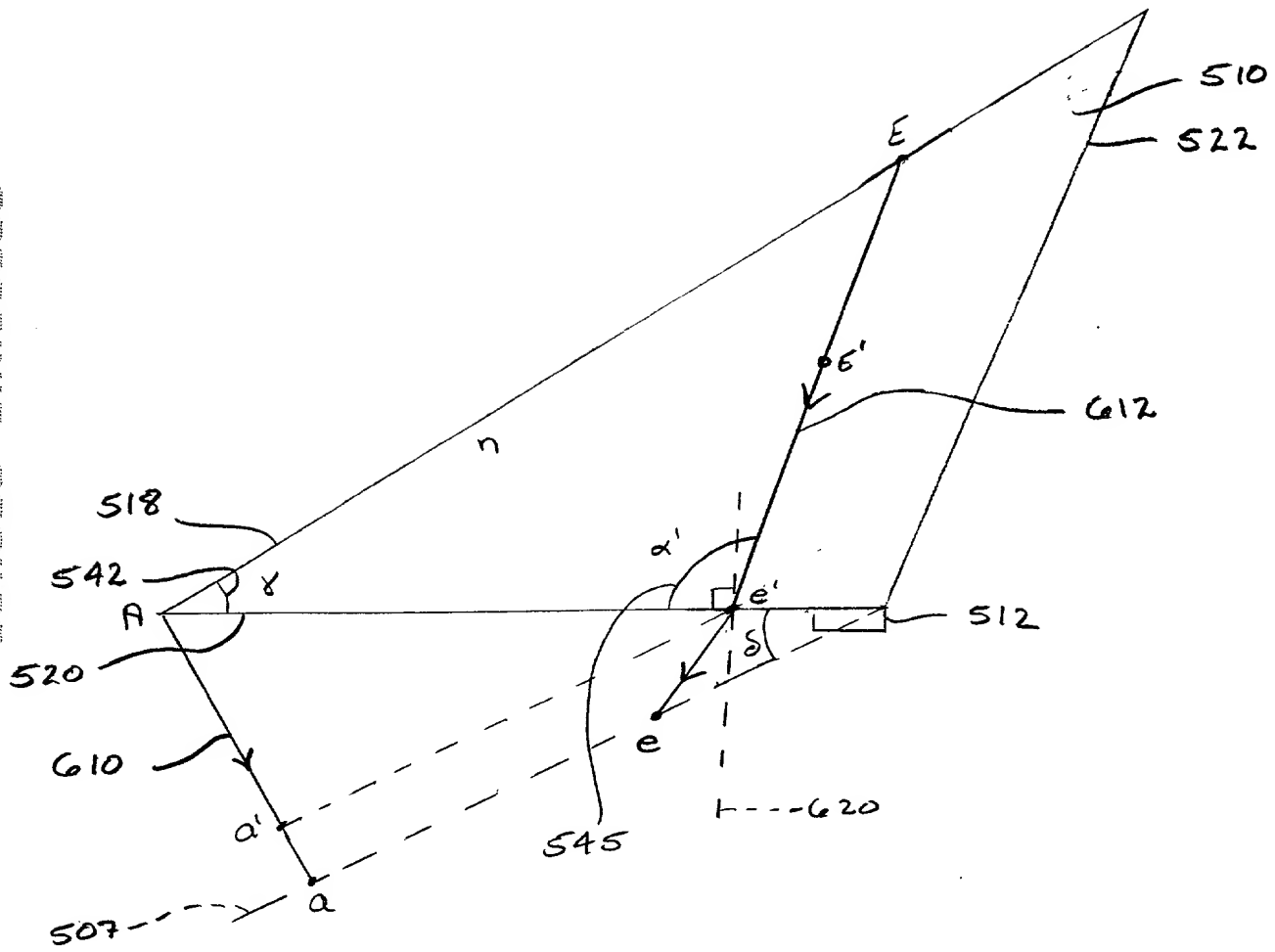## FOR UTILITY PATENT APPLICATION

AS A BELOW-NAMED INVENTOR, WE HEREBY DECLARE THAT:

Our residence, post office address, and citizenship are as stated below next to our names.

We believe we are the original, first and joint inventors of the subject matter which is claimed and for which a patent is sought on the invention entitled: METHOD AND APPARATUS FOR REDUCTION OF TRAPEZOIDAL DISTORTION AND IMPROVEMENT OF IMAGE SHARPNESS IN AN OPTICAL IMAGE CAPTURING SYSTEM, the specification of which is attached hereto unless the following box is checked:

☐   was filed on as United States Application Serial No. or PCT International Application No. and was amended on (if applicable).

WE HEREBY STATE THAT I HAVE REVIEWED AND UNDERSTAND THE CONTENTS OF THE ABOVE-IDENTIFIED SPECIFICATION, INCLUDING THE CLAIMS, AS AMENDED BY ANY AMENDMENT REFERRED TO ABOVE.

We acknowledge the duty to disclose information which is material to the patentability as defined in 37 C.F.R. § 1.56.

We hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed:

Application No.	Country	Date of Filing (day/month/year)	Priority Claimed?
*			☐Yes ☐No

We hereby claim benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below:

Application Serial No.	Filing Date

We hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, we acknowledge the duty to disclose information which is material to patentability as defined in 37 C.F.R. § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

Application Serial No.	Filing Date	Status
		☐Patented ☐Pending ☐Abandoned

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Docket No. 404302000400

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We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

We further declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct. Executed on:

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